Probing tensor terms of the Skyrme energy density functional in rotating nuclei

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Outline

Why focus on the tensor part ?

- The tensor force is a key ingredient of all vacuum NN interaction
- It has an impact on the shell structure of stable and unstable nuclei
- Until recent, it was however mostly absent in self-consistent mean-field methods

  T. Otsuka PRL 97 (2006) 162501 ; B. A. Brown, PRC 74 (2006) 061303 ; G. Colo PLB 646 (2007) 227 ; T. Lesinski PRC 76 (2007) 014312 ;

  M. Zalewski PRC 77 (2008) 024316 ; W. Zou PRC 77 (2008) 014314
- Its contribution to s.p. energies is dependent on the filling of shells : it (nearly) vanishes in spin-saturated nuclei and might be significant if only one level out of the two spin-orbit partners is filled
- Deformation breaks this simple picture (M. Bender PRC 80 (2009) 064302)

The Skyrme energy density functional in 1 slide

- The energy of the atomic nucleus can be expressed by means of an energy density functional (EDF)

$$\mathcal{E} = \mathcal{E}_{\text{kin}} + \mathcal{E}_{\text{Sk}} + \mathcal{E}_{\text{pairing}} + \mathcal{E}_{\text{Coulomb}} + \mathcal{E}_{\text{corr}}$$

- The Skyrme EDF can be considered to be generated by a zero-range 2-body effective interaction including a density-dependent term

$$\begin{aligned}\mathcal{E}_{\text{Sk}} = \int d^3r \sum_{t=0,1} \Big\{ & C_t^{\rho}\rho_t^2 + C_t^{s}\mathbf{s}_t^2 + C_t^{\Delta\rho}\rho_t\Delta\rho_t + C_t^{\nabla s}(\nabla\cdot\mathbf{s}_t)^2 + C_t^{\Delta s}\mathbf{s}_t\cdot\Delta\mathbf{s}_t \\ & + C_t^{T}\Big(\mathbf{s}_t\cdot\mathbf{T}_t - \sum_{\mu,\nu=x,y,z} J_{t,\mu\nu}J_{t,\mu\nu}\Big) + C_t^{\nabla\cdot J}(\rho_t\nabla\cdot\mathbf{J}_t + \mathbf{s}_t\cdot\nabla\times\mathbf{j}_t) + C_t^{\tau}(\rho_t\tau_t - \mathbf{j}_t^2) \\ & + C_t^{F}\Big[\mathbf{s}_t\cdot\mathbf{F}_t - \tfrac{1}{2}\Big(\sum_{\mu=x,y,z} J_{t,\mu\mu}\Big)^2 - \tfrac{1}{2}\sum_{\mu,\nu=x,y,z} J_{t,\mu\nu}J_{t,\nu\mu}\Big]\Big\}\end{aligned}$$

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- The Skyrme EDF can be considered to be generated by a zero-range 2-body effective interaction including a density-dependent term
- Unfortunately, the density in the EDF is not god-given, hence we must use the variational principle

$$\delta\mathcal{E} = 0$$

- How about rotational bands ? We can use the self-consistent cranking approximation

$$\mathcal{E}_{\omega} = \mathcal{E} - \omega\langle\hat{J}_x\rangle$$

And why look at tensor terms in superdeformed bands?

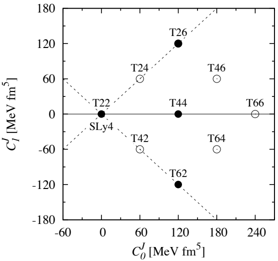
$$\mathcal{E}_{\text{Sk}} = \int \mathrm{d}^3 r \sum_{t=0,1} \Big\{ C_t^{\rho} \rho_t^2 + C_t^{s} \mathbf{s}_t^2 + C_t^{\Delta\rho} \rho_t \Delta \rho_t + C_t^{\nabla s} (\nabla \cdot \mathbf{s}_t)^2 + C_t^{\Delta s} \mathbf{s}_t \cdot \Delta \mathbf{s}_t$$

$$+ C_t^{T} \Big(\mathbf{s}_t \cdot \mathbf{T}_t - \sum_{\mu,\nu=x,y,z} J_{t,\mu\nu} J_{t,\mu\nu} \Big) + C_t^{\nabla \cdot J} (\rho_t \nabla \cdot \mathbf{J}_t + \mathbf{s}_t \cdot \nabla \times \mathbf{j}_t) + C_t^{\tau} (\rho_t \tau_t - \mathbf{j}_t^2)$$

$$+ C_t^{F} \Big[\mathbf{s}_t \cdot \mathbf{F}_t - \tfrac{1}{2} \Big(\sum_{\mu=x,y,z} J_{t,\mu\mu} \Big)^2 - \tfrac{1}{2} \sum_{\mu,\nu=x,y,z} J_{t,\mu\nu} J_{t,\nu\mu} \Big] \Big\}$$

1. What is the evolution of the tensor terms and the effect of different parameterizations in a rotating nucleus ?
2. What is the influence of the additional “time-odd“ terms enter because of the tensor interaction ?

Some technical details ...

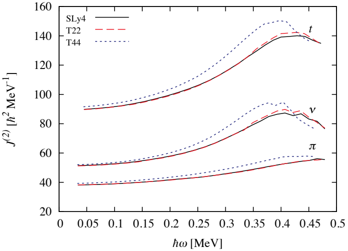


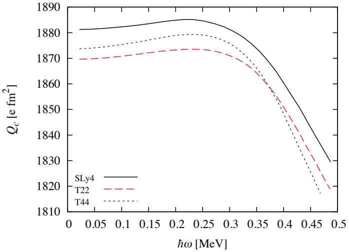
- Set of parameterizations based on the same protocol as the SLyx parameterization (T. Lesinski PRC 76 (2007) 014312)
- T22 has vanishing tensor terms at *sphericity* and should therefore have properties close to that of SLy4
- T44 has the same C_1^J coupling constant as T22, but a C_0^J coupling constant of 120 MeV fm^5

Technical details

- HFB plus self-consistent cranking calculations plus LN
- T22 and T44 were used in the p-h channel ($C_t^{\Delta s} = C_t^{\nabla s}$=0 unless otherwise indicated)
- a density-dependent δ-interaction with strength -1250 MeV fm^{-3} was used in the p-p channel

The ground superdeformed band in ^{194}Hg





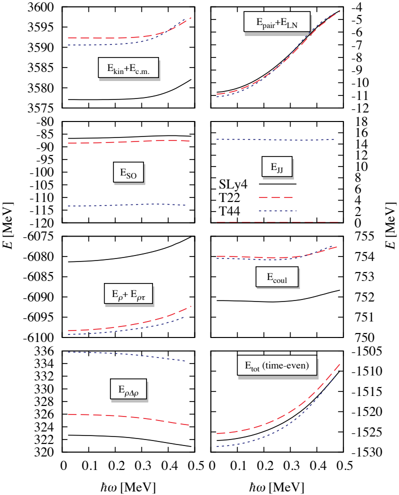
The dynamical moments of inertia, $\mathcal{J}^{(2)} = \frac{\partial J_0}{\partial \omega}$

- Little difference between SLy4 and T22, even though we're far away from sphericity
- Difference between SLy4 and T22 is caused by neutrons
- For T44, the $\mathcal{J}^{(2)}$ increases faster and the plateau occurs at lower $\hbar\omega$

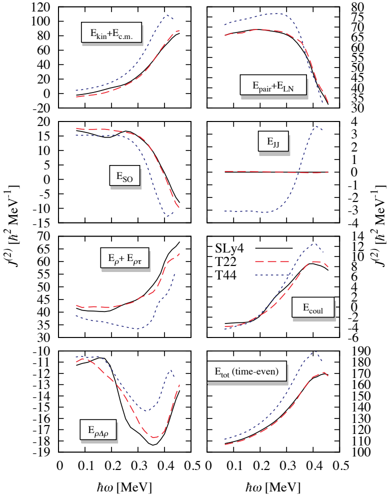
The charge quadrupole moments Q_c

- all charge quadrupole moments display the same behavior, staying more or less constant up to a certain $\hbar\omega$ until they start decreasing under the influence of rotations
- very little difference between SLy4, T22 and T44

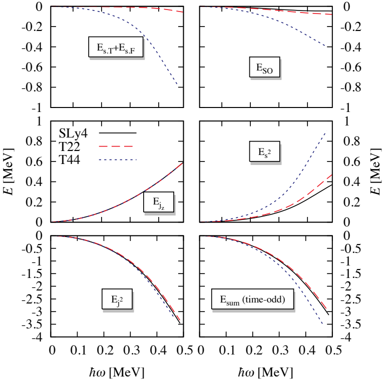
Contributions to the total energy : time-even



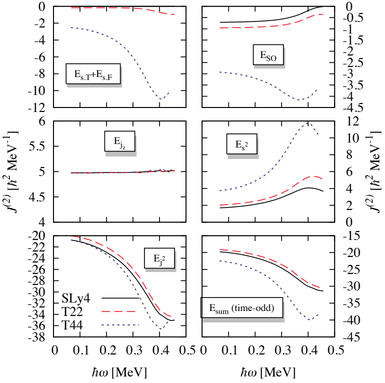
Contributions to the total $\mathcal{J}^{(2)}$: time-even



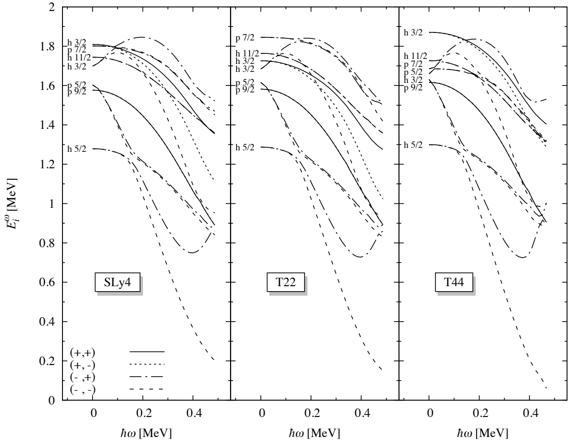
Contributions to the total energy : time-odd



Contributions to the total $\mathcal{J}^{(2)}$: time-odd

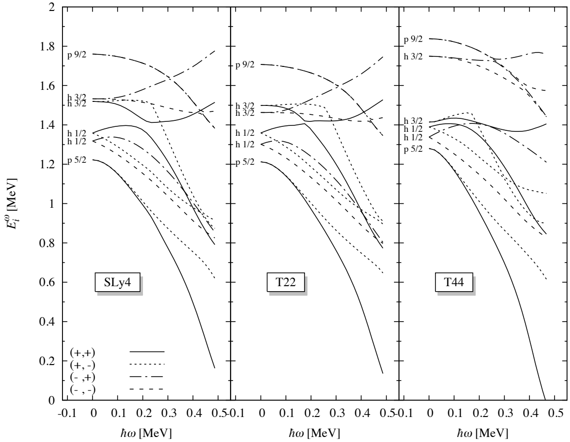


Neutron quasiparticle Routhians



- The position and ordering of the quasiparticles evolves when moving from SLy4 to T22 to T44
- This influences the initial interactions between the Routhians, which in turn influences their alignments and the position of consequent interactions.

Proton quasiparticle Routhians



- Similar conclusions as for the neutron quasiparticle Routhians
- For both proton and neutron quasiparticle Routhians, we observe a faster alignment with $\hbar\omega$ for T44 as compared to SLy4 and T22

Conclusions

- The influence of the tensor terms in the Skyrme EDF on the calculated properties is a subtle one : on the one hand, there is the direct influence because of the presence of the tensor terms and their specific value of the coupling constants ; on the other hand, there is the indirect influence on other terms through self-consistency
- Overall, no “dramatic” changes are observed when the tensor terms are included and when a consistently constructed parameterization is used. The general features of our results (such as shape of the $\mathcal{J}^{(2)}$, charge quadrupole moments, ...) are preserved with the TIJ parameterizations, pointing towards the robustness of the method.
- Small differences in the quasiparticle spectrum at J_0=0 influence the alignments and the $\mathcal{J}^{(2)}$
- We have also studied the influence of the coupling constants of the additional time-odd terms that enter because of the tensor interaction. A study of finite-size instabilities as well as the influence of the tensor terms in odd nuclei is underway.